Antibaryons in massive heavy ion reactions: Importance of potentials

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Abstract

In the framework of RQMD we investigate antiproton observables in massive heavy ion collisions at AGS energies and compare to preliminary results of the E878 collaboration. We focus here on the considerable influence of the *real* part of an antinucleon–nucleus optical potential on the $\bar{p}$ momentum spectra.

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Antibaryon production is a promising observable for collective effects in nucleus–nucleus collisions. On the other hand, $\overline{N}$'s suffer strong final–state interactions. These interactions have two components which can be related to the $\overline{N}$ self–energy in matter: collisions and annihilation on baryons[1] (imaginary part, semiclassically given by $2\mathrm{Im}V = \sigma v \rho$) and a piece in the real part ($\mathrm{Re}V = t_{\mathrm{NN}}\rho$ in the impuls approximation). In the semiclassical limit the real part of the self-energy can be approximated by potential–type interaction[2] or a mean field.

Here we will focus on the effect of the real part. The motivation is that the long–range force of baryons acting on a $\bar{p}$ is expected to be stronger than for protons since the Lorentz–scalar and the Lorentz–vector parts of a meson exchange potential now have the same sign. The influence of baryonic mean–fields on baryons and mesons is well established. Therefore there should also be some influence on $\bar{p}$'s.

The substantial impact of mean–fields on particle spectra was studied earlier [3, 4]. Following these ideas, we now investigate observables in nucleus–nucleus collisions, where $\overline{B}B$-potentials come into play. For this purpose, we employed a simple model–interaction, knowing that this choice is far from being unique.

In principle, one has to calculate the medium–dependent mean–field and the cross–section selfconsistently to understand $\overline{N}$ behaviour in matter. We calculate the forces acting on a $\overline{N}$ in a baryonic medium only *after* freeze–out. However, by taking the free interaction — annihilation, elastic scattering, non–annihilating inelastic channels — for $\overline{N}N$ in the collision term during the dynamical evolution the real potential is included effectively. Our approach is similar in its spirit to the usual treatment of the Coulomb distortion of particle spectra which is also restricted to final–state interactions[5]. Addition of free interactions and mean–field contribution would cause

double counting of interactions: any geometric cross section will appear as a larger physical cross section if the particles' trajectories are bent due to attractive forces. Fig. 1 shows this effect for our model potential. Due to the strong attraction for the $\bar{B}B$ case, a reduced geometric annihilation cross section suffices to account for the measured free annihilation probability in binary $\bar{N}N$ reactions. This is in rough correspondence to phenomenological models of $\bar{p}p$ interaction [6], where the characteristic range of the imaginary potential is chosen to be less than 1 fm, which corresponds to a disc much smaller than the free annihilation cross section. For the same reason the insertion of *free* cross sections in the collision term of Vlasov–type models seems questionable.

The great success of Dirac equation optical model calculations for pA scattering [7] led us to using these relativistic potentials (Lorentz–scalar and vector interaction) with Yukawa functions as form factors — applying G–parity transformation — for the $\overline{p}$ case [1]: The mass paramters are $\mu_V = 3.952$ fm^{-1} and $\mu_S = 2.787$ fm^{-1}, the coupling constants are $g_V = 13.5$ MeV fm and $g_S = 10.9$ MeV fm. In line with [7] we used gaussians as baryon profiles with a mean square radius of 0.8 fm. The central part of an effective Schrödinger equivalent potential (SEP) is constructed from the above potentials:

$$U_{\mathrm{SE}} = \frac{1}{2E}(2EU_V + 2mU_S - U_V^2 + U_S^2),$$

where E is the total energy of the incident particle.

The $\overline{p}$'s are produced and propagated with the usual RQMD simulation [10] (NN-potentials are switched off, i. e. pure cascade mode) until they undergo the last strong interaction. Afterwards the trajectories of the $\bar{p}$'s are calculated under the influence of the relativistic optical potentials, while the remaining particles continue to interact within the cascade calculation.

For $\overline{N}N$ distances, smaller than the corresponding annihilation cross section, the real potential should not show an effect, since the huge imaginary part absorbs the particular $\overline{p}$ anyhow. We have chosen 1.5 fm as cutoff distance corresponding to an averaged $\overline{p}p$-annihilation cross section of ≈ 70 mb.

The Schrödinger equivalent potential with the above parameters results in a mean $\overline{p}$-potential in nuclear matter at groundstate density of about -250 MeV ($p_{\overline{p}} = 0$ GeV/c), increasing with energy towards -170 MeV at $p_{\overline{p}} = 1$ GeV/c. These values are much more in accord with estimations on the basis of dispersion relations [11] than just taking the sum of the scalar and vector potentials without any cutoff. The actual (averaged) SE-potential of the $\overline{p}$'s at freeze–out is about -70 MeV in central $Au + Au$ collisions at 10.7 GeV. We have also studied the influence of Coulomb–effects on the $\bar{p}$ momentum spectrum. It shows that the average potential is less than -10 MeV and therefore of less importance [2].

For central collisions of $Au + Au$ at 10.7 GeV we find a substantial change in the final phase space distribution of the $\overline{p}$'s at low–p_t, deviating from results of a pure cascade, due to the potential interaction during the last stage of the collision. Without potentials, we find a clearly nonthermal spectrum with a dip at midrapidity for $p_t = 0$. Due to the strong momentum dependence of the $\overline{p}p$-annihilation cross section, $\overline{p}$'s with low transverse momentum are suppressed.

Figure 2 shows the p_t-spectrum at midrapidity ($-0.4 < y < 0.4$) of the antiprotons with and without the inclusion of potential interaction. With potential interaction

[1] Optical model calculations for intermediate energy antiproton scattering like in [8, 9] cannot provide unambigous values of the real part of the optical potential, since the imaginary part dominates the behavour.

[2] The effect may be relevant for pions: in the above system the ratio π^-/π^+ for $p_t < 100$ MeV increases according to our simulation by 25 percent due to the Coulomb potential.

included the dip at low p_t gets filled without changing the shape of the spectrum at higher momenta. Figure 3 shows the invariant multiplicity $\frac{1}{2\pi p_t}\frac{\mathrm{d}^2N}{\mathrm{d}y\mathrm{d}p_t}$ of $\overline{p}$'s with $p_t < 200$ MeV. RQMD 1.07 calculations with and without potentials are compared to preliminary data of the E878 collaboration[12]. in addition to the presented result for the proposed model interaction we calculated the effect for the same potentials arbitrarily reduced by 50 %. Still the dip at midrapidity vanishes although the change is less pronounced. Note that the p_t-integrated spectrum at midrapidity is affected by less than 25 percent in comparison to the calculation without potential interaction.

The theoretical understanding of $\bar{p}$ propagation in a baryon–dense medium is far from satisfying. For instance, the absorption strength differs by orders of magnitude if one compares different transport calculations[$11, 13-18$]. Our study should be seen as a first step on the way towards a self-consistent treatment of the real and the imaginary parts of the $\overline{N}N$ potential in a transport theoretical calculation.

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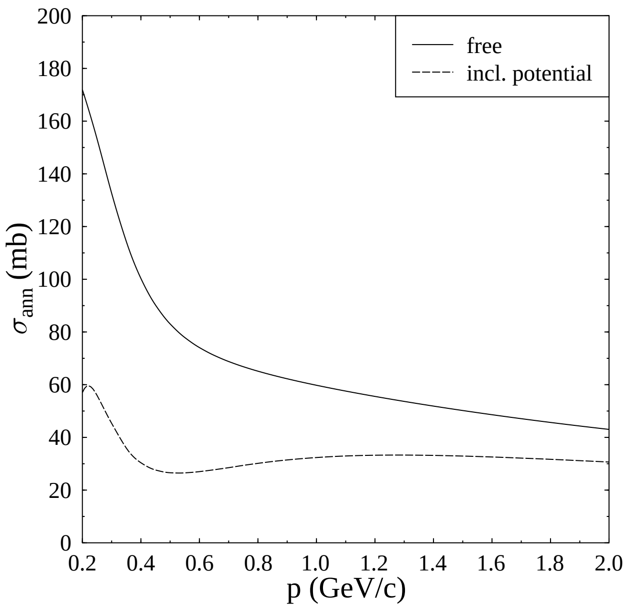

Figure 1: $\overline{p}p$ annihilation cross section as a function of $p_{\rm lab}$. Parametrisation of the free measured cross section (full line) and the corrected value, if potential interaction is added (dashed line).

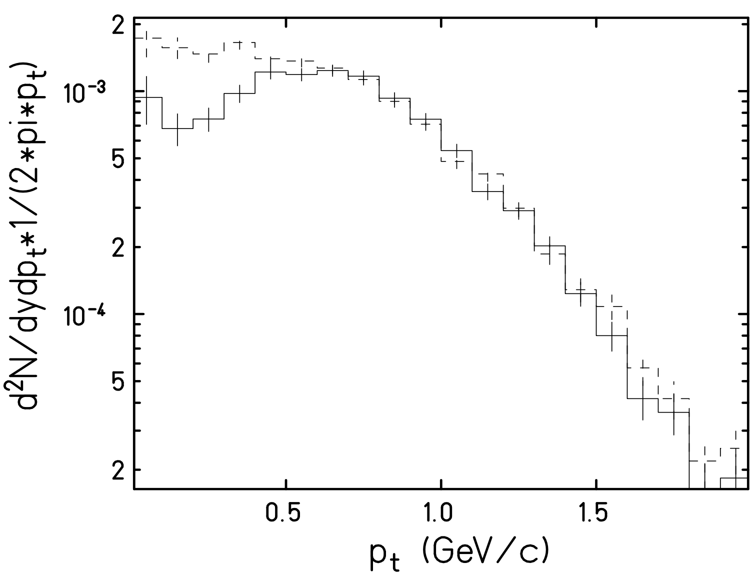

Figure 2: Invariant p_t–spectrum of the $\overline{p}$'s at midrapidity ($-0.4 < y < 0.4$) for central reactions of $Au + Au$ ($b < 4$ fm) at 10.7 GeV/u. Shown is the spectrum of the RQMD calculation (full line) and with an additional optical potential (dashed line).

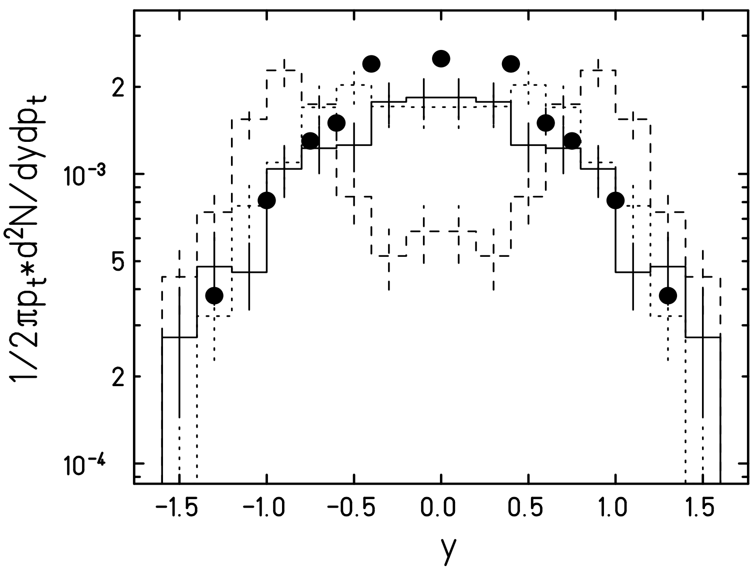

Figure 3: Invariant rapidity–distribution of the $\overline{p}$'s with $p_t < 200$ MeV for $Au+Au$ ($b <$ 4 fm) at 10.7 GeV/u. Shown is the RQMD calculation (dashed line), with the additional optical potential (full line) and the 50 % reduced potential (points). Preliminary data (full circles) from [12] (the error bars are omitted).